KTH ROYAL INSTITUTE OF TECHNOLOGY

Optimal Segmented Efficiency in Hydrosystem Area Equivalents to Capture Real Production Peaks

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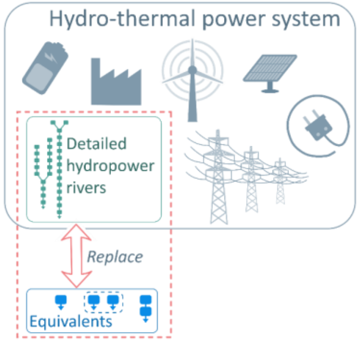
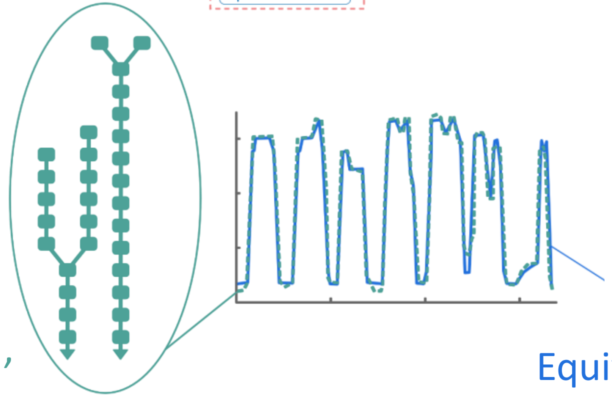
Introduction

- Hydropower Equivalent
  - Power/energy system models
  - Simplification
  - Fast

- **Aim**: mimic the power production of a more detailed hydropower model
  - Same input → same output

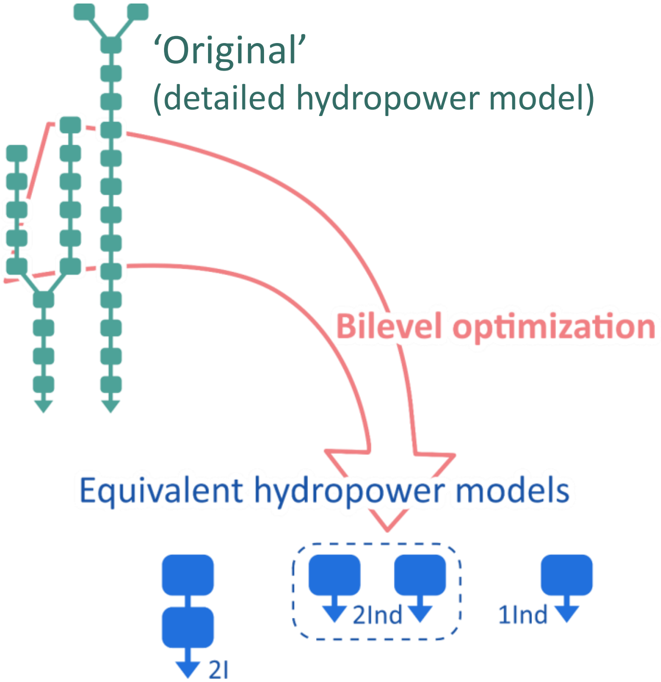




‘Original’
(detailed hydropower model)

Equivalent
hydropower model

From Detailed system to Equivalent?



- Bilevel optimization to minimize production difference
  - Upper-level objective function:

$$\min\left(power^{E} - power^{D}\right)^{2}$$

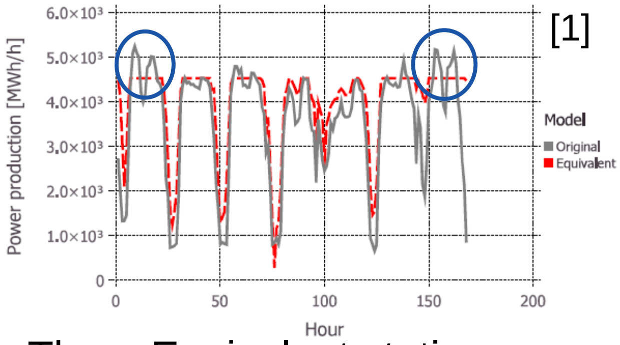
  - Lower-level: Equivalent hydropower operation simulation

→ Equivalent model parameters

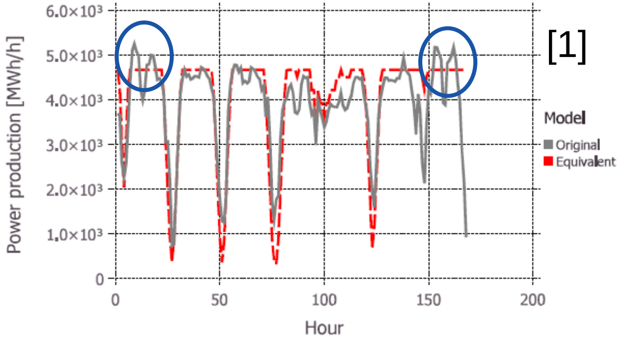
- Different methods to solve the bilevel problem
- Different formulations of the Equivalent model

Problem to solve

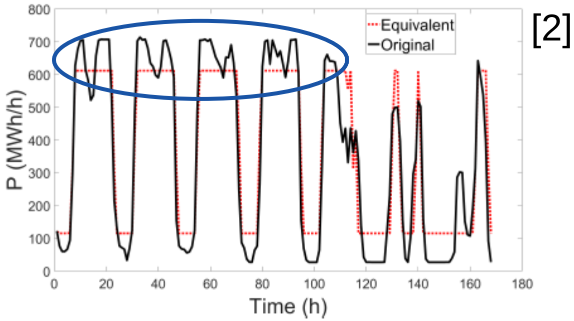
- Production peaks
- Example from two earlier papers (2017, 2020)



Three Equivalent stations,
10 segments in PQ-curve



Single Equivalent station,
5 segments in PQ-curve

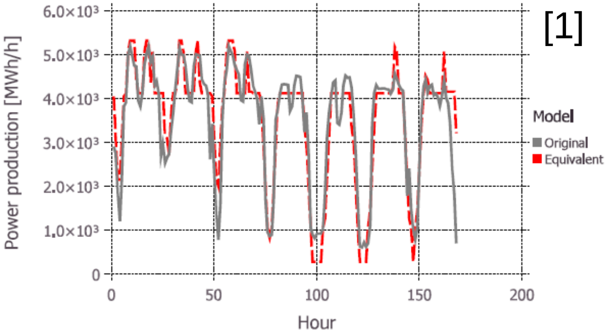


Single Equivalent station,
1 segment in PQ-curve

[1] E. Blom, D. Risberg, L. Söder, "*Performance of Multi-scenario Equivalent Hydropower Models2*, Electric Power Systems Research (2020)
[2] D. Risberg, L. Söder, " Hydro power Equivalents of Complex River Systems", 2017 IEEE Manchester PowerTech (2017)

Problem to solve

- Production peaks
- Example from two earlier papers (2017, 2020)



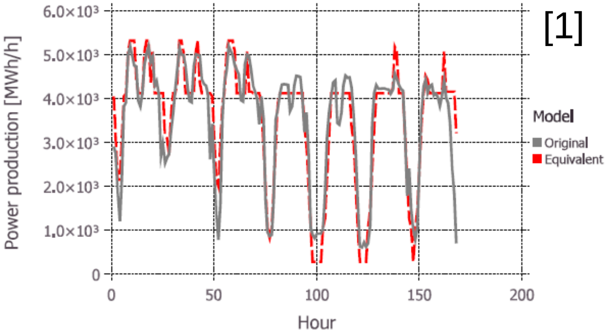
[1]

Two Equivalent stations,
2 segments in PQ-curve*

[1] E. Blom, D. Risberg, L. Söder, “*Performance of Multi-scenario Equivalent Hydropower Models2*, Electric Power Systems Research (2020)

Problem to solve

- Production peaks



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Two Equivalent stations,
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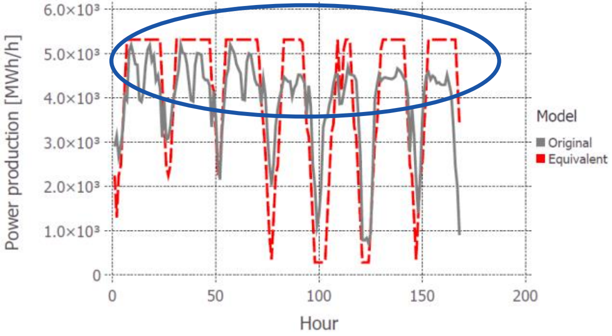


Overestimation instead of underestimation

[1] E. Blom, D. Risberg, L. Söder, "*Performance of Multi-scenario Equivalent Hydropower Models2*, Electric Power Systems Research (2020)

Conclusions

- Accurate production peaks important for:
  - Integration studies of variable renewable energy
  - Peak capacity estimations

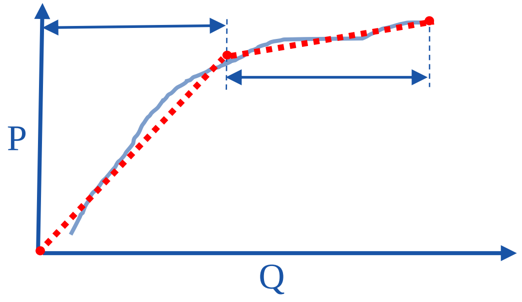
- Capture production peaks?
  1. Multiple segments to avoid flat production levels
  2. Optimize PQ-relation and segmentation

← New method (with PSO)

- However:
  - Average hourly accuracy might decrease
  - Average accuracy vs peak accuracy

Old method for segmentation

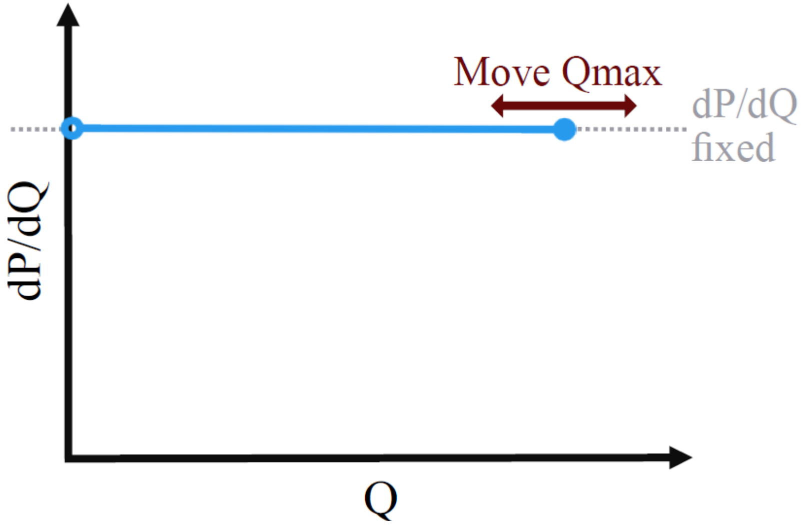
- Marginal production function $\mu = {}^{dP}/_{dQ}$



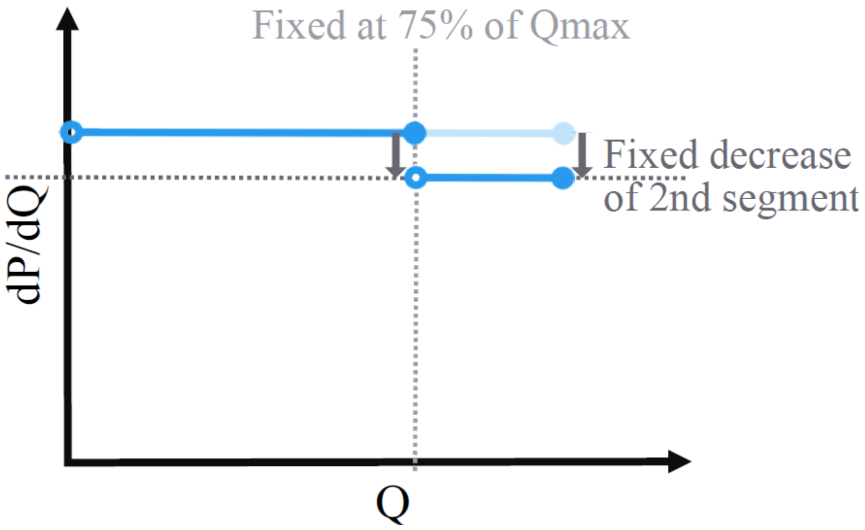
- Assume first segment μ_1^E is equal to the average μ_1^D of the Original detailed system
- Assume discharge is divided into two segments at fixed points
  - First segment up to 75% of total maximum
  - Second segment from $75 - 100\%$ of total maximum
- Decrease value of μ_2^E with 1% compared to first segment
  - Alternative: Decrease value of μ_2^E with 5% compared to first segment

Old method for segmentation

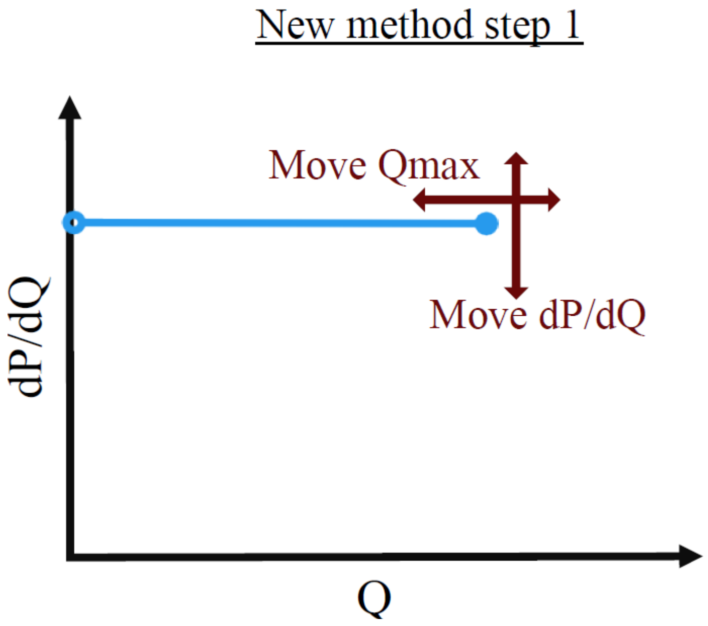
Old method step 1

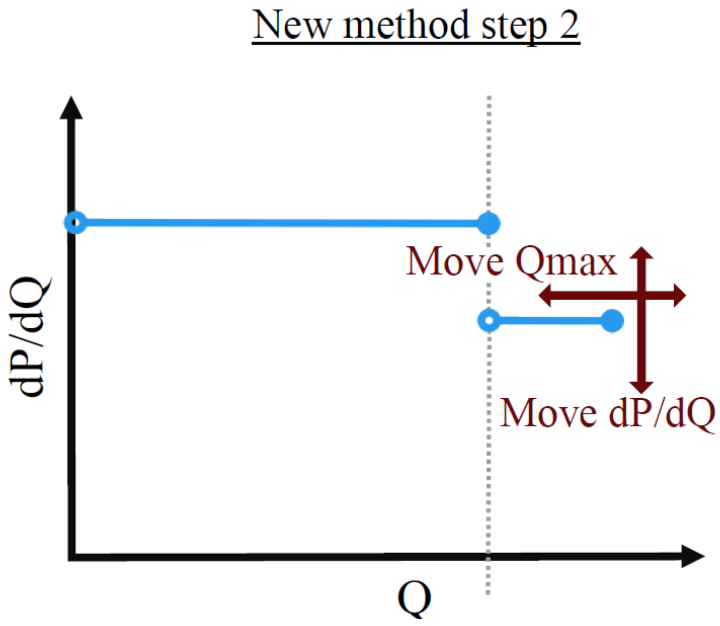


Old method step 2



New method for segmentation





New method for segmentation

- Step 2: New upper-level objective function focused on peak hours

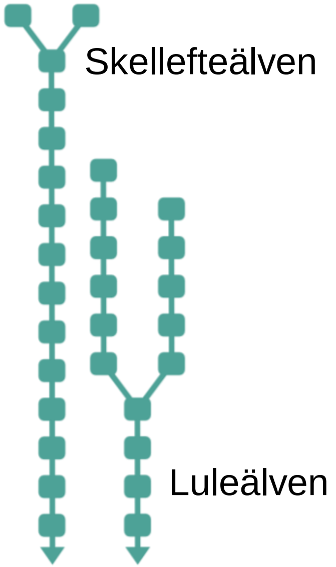
$$f^{up} = \sum_t \left(power_t^E - Power_t^D\right)^2 + \sum_{t*} \left(power_t^E - Power_t^D\right)^2$$

$t*$: hours during which $Power_{wt}^D \geq 0.9 \cdot \max(Power_{wt}^D)$

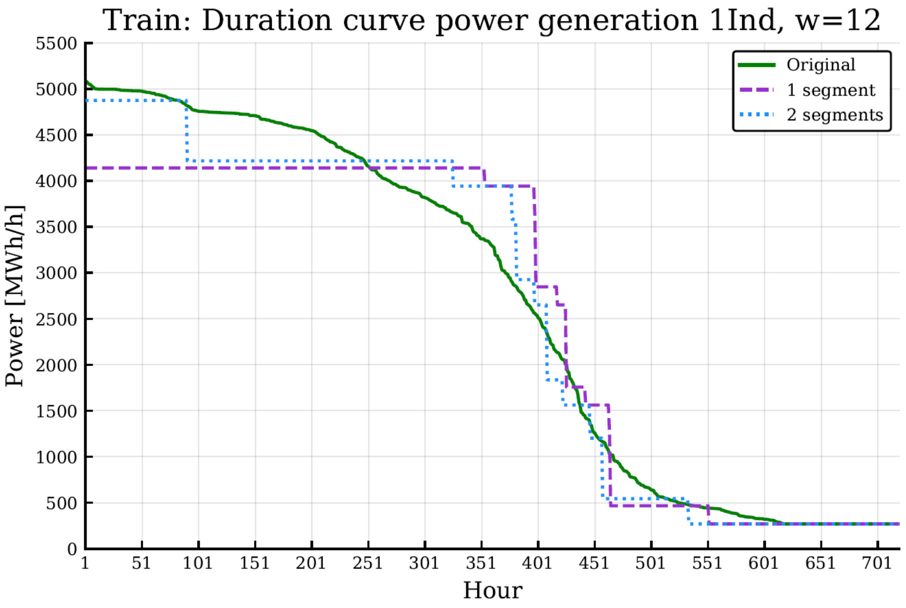
- Without new function, second discharge segment almost never utilized

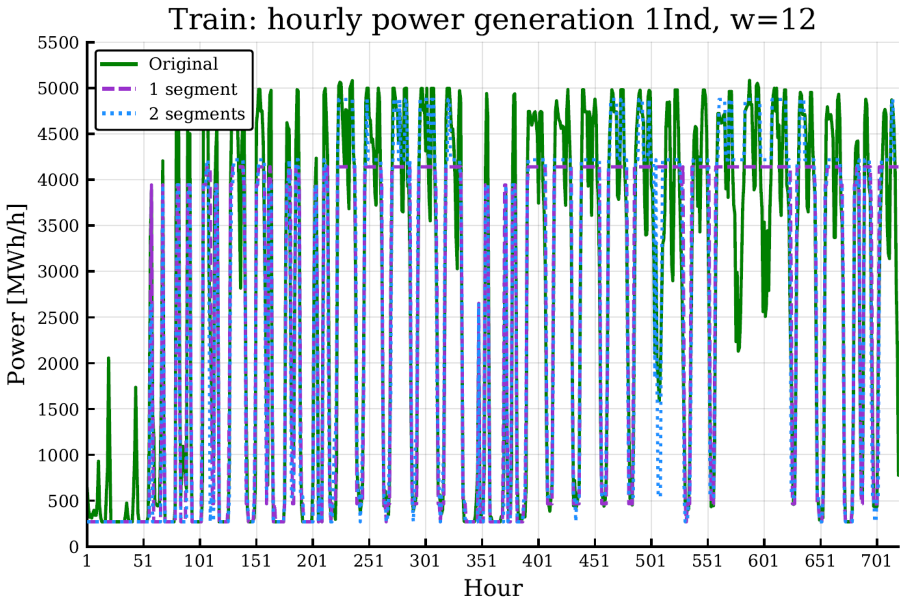
Case study

- Case study: SE1
  - Luleälven and Skellefteälven
  - 30 hydropower stations, approx. 5500 MW
- Training and testing data sets
  - Each 720 hours
- Single Equivalent station
  - Old method 2 segments (1% and 5%)
  - New method 1 and 2 segments
  - *Middle ground*: old method for segment 1, new method for segment 2



Results – new method





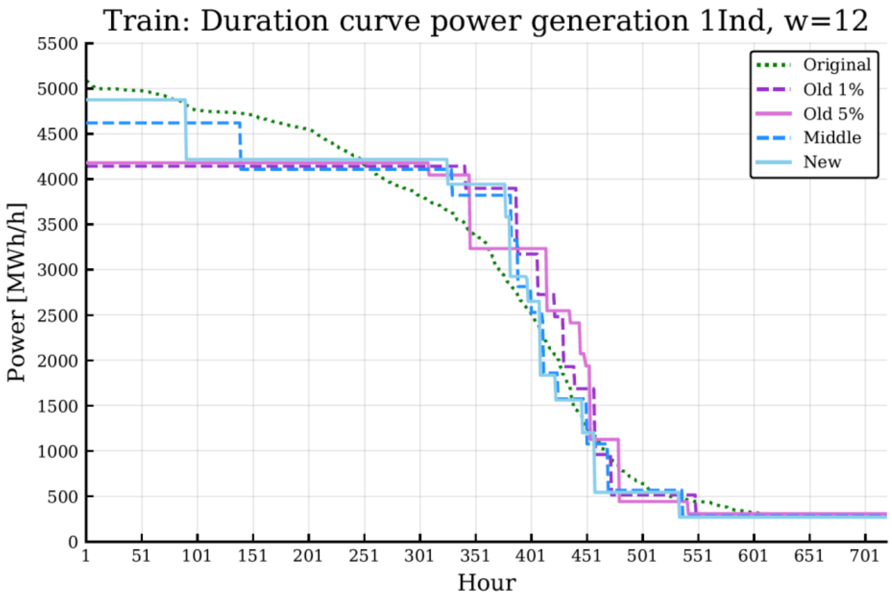
Results on training data

Equivalent	Hourly difference	Scenario difference	$\min(power^E - power^D)^2$ 'Fitness'
Baseline (aggregation)	15.57%	2.70%	1.24E+10
Old 1%	8.32%	6.05%	4.01E+09
Old 5%	**7.75%**	5.44%	3.47E+09
Middle 1 segment	9.01%	6.83%	4.64E+09
Middle 2 segments	8.19%	4.09%	4.35E+09
New 1 segment	8.45%	5.96%	4.23E+09
New 2 segments	7.94%	**3.06%**	3.97E+09

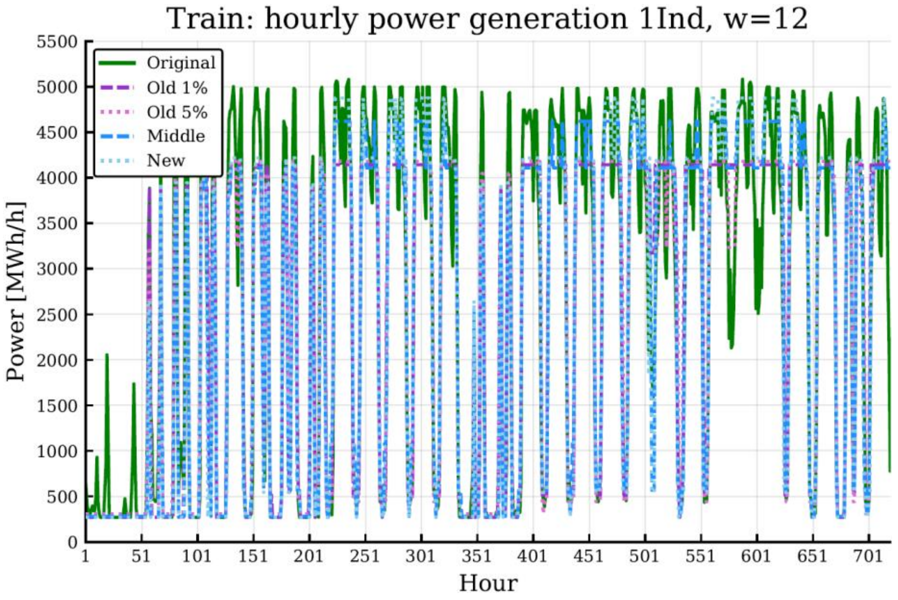
Results on testing data

Equivalent	Hourly difference	Scenario difference	$\min(power^E - power^D)^2$ 'Fitness'
Baseline (aggregation)	15.12%	0.50%	5.27E+09
Old 1%	8.84%	7.37%	1.98E+09
Old 5%	**8.21%**	6.27%	1.55E+09
Middle 1 segment	9.36%	8.88%	2.15E+09
Middle 2 segments	8.32%	4.22%	1.90E+09
New 1 segment	9.14%	7.46%	2.14E+09
New 2 segments	8.42%	**2.70%**	2.04E+09

Comparison

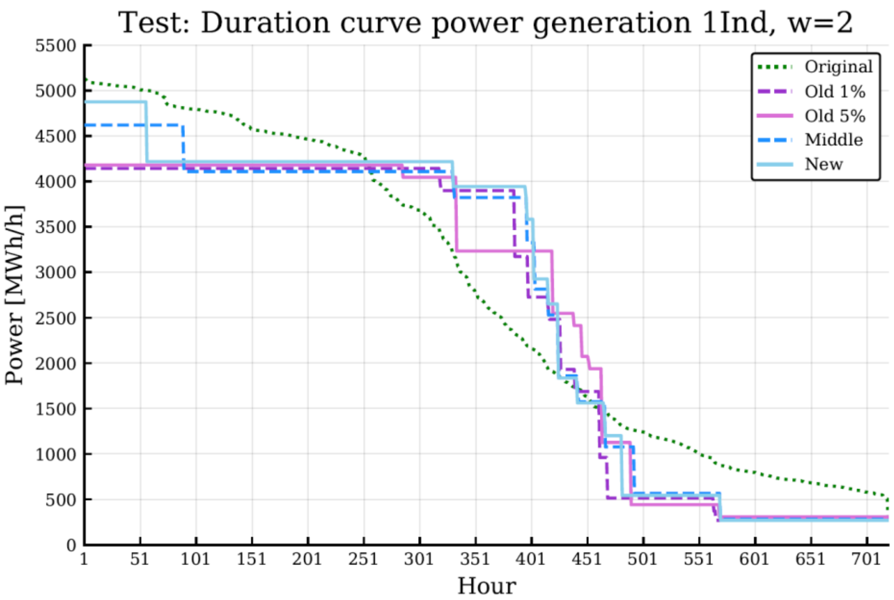


Train: Duration curve power generation 1Ind, w=12
Power [MWh/h]
Hour
Original
Old 1%
Old 5%
Middle
New



Train: hourly power generation 1Ind, w=12
Power [MWh/h]
Hour
Original
Old 1%
Old 5%
Middle
New

Comparison


Test: Duration curve power generation 1Ind, w=2
Power [MWh/h]
Hour
Original
Old 1%
Old 5%
Middle
New
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
1
51
101
151
201
251
301
351
401
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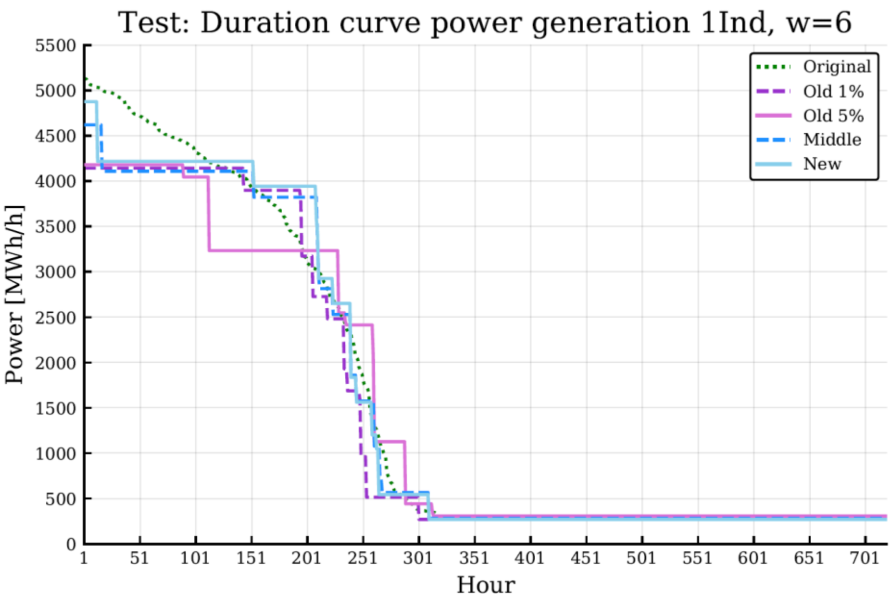
501
551
601
651
701


Test: Duration curve power generation 1Ind, w=6
Power [MWh/h]
Hour
Original
Old 1%
Old 5%
Middle
New
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
1
51
101
151
201
251
301
351
401
451
501
551
601
651
701

Conclusions

- New method has:
  - lower accuracy in hourly power production
  - higher accuracy for production peaks
  - higher accuracy for total power production
- However, not all peaks are captured
- Future work
  - Add more segments
  - Compute all segments in one step
  - Modify upper-level objective function

References and more information

[1] E. Blom, D. Risberg, L. Söder, “*Performance of Multi-scenario Equivalent Hydropower Models*”, Electric Power Systems Research (2020)

[2] D. Risberg, L. Söder, *“ Hydro power Equivalents of Complex River Systems”*, 2017 IEEE Manchester PowerTech (2017)

[3] E. Blom, L. Söder, “*Computation of Multi-Scenario Hydropower Equivalents Using Particle Swarm Optimization”*, 2020 EEEIC / I&CPS Europe (2020)

[4] P. Nugroho Prianto, E. Blom, L. Söder , “*Evaluation of Hydropower Equivalents Parameters Over Time”*, 6th International Conference on Green Energy and Applications (2022)

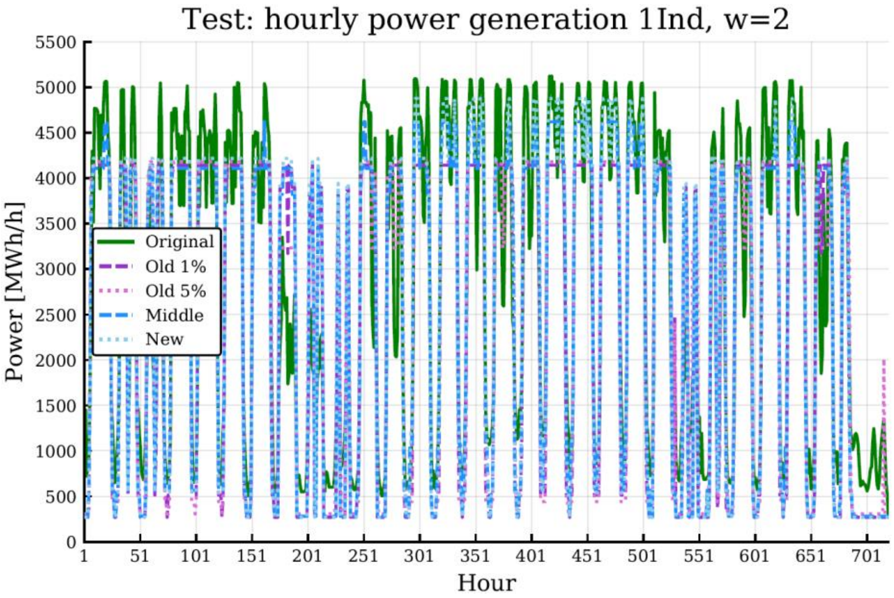
[5] E. Blom, L. Söder, “*Evaluation of Different Computational Methods and Formulations for Hydropower Equivalents”*, EnergyCon2022 (2022)

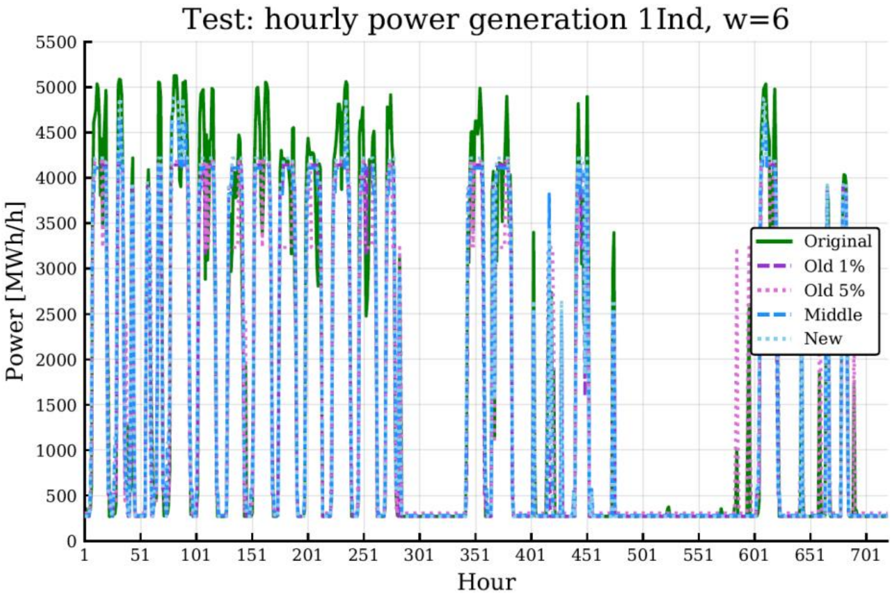
Thank you!

Questions?

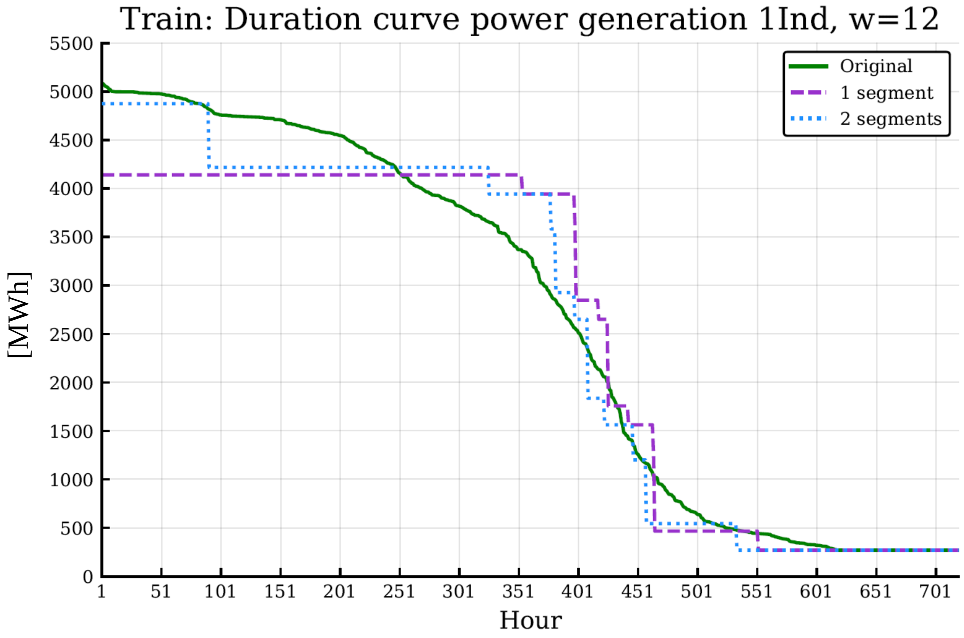
Comparison

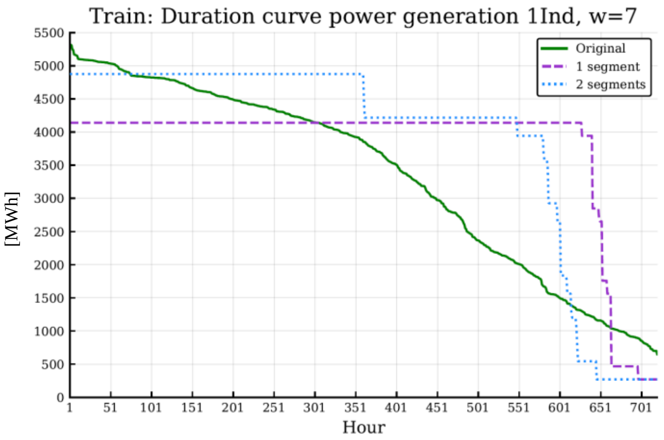
Power curves, corresponding to duration curves on slide 17

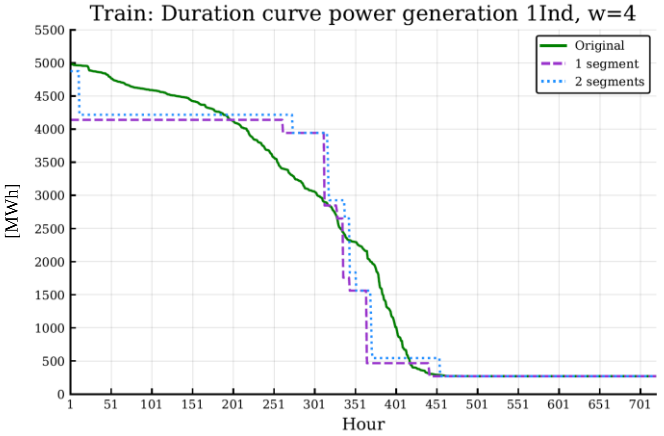




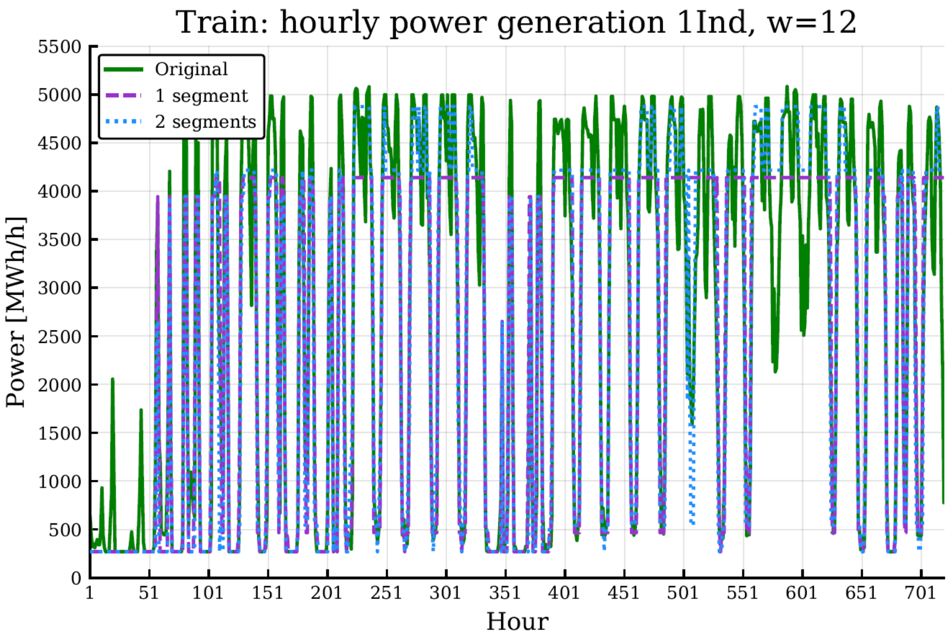
Results – new method

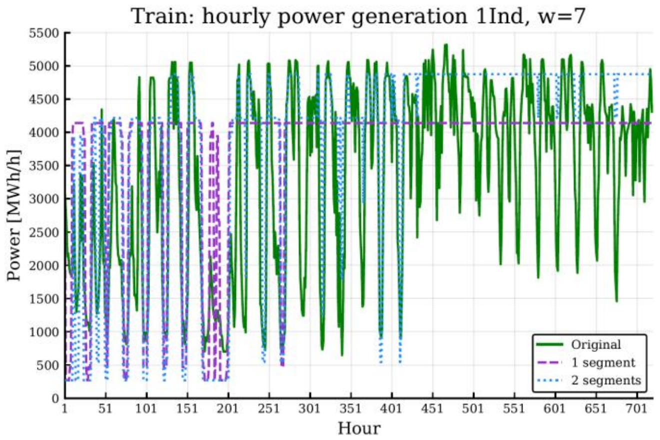


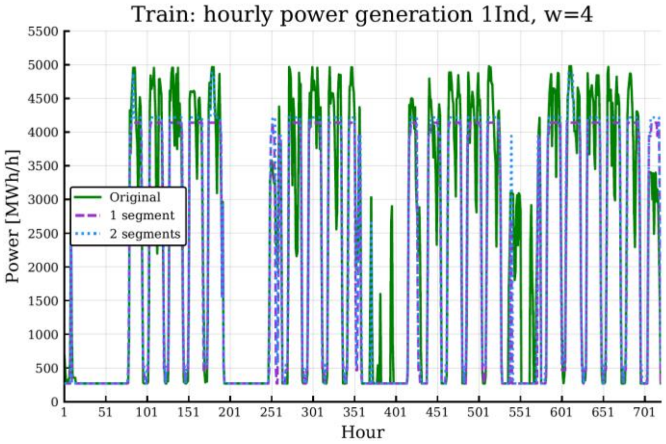




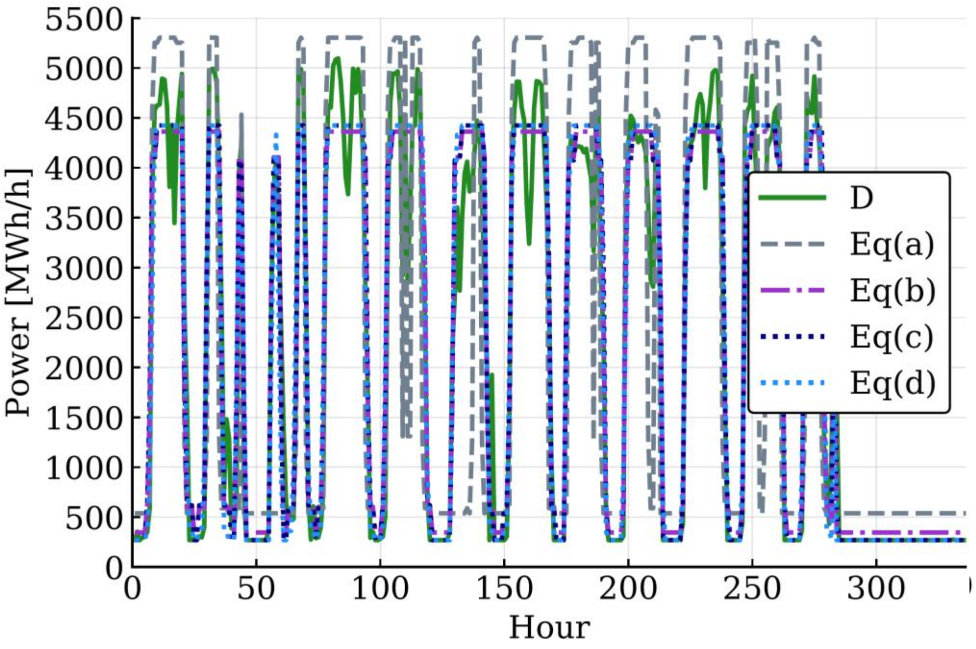
Results – new method







Baseline aggregation example from [5]



- Power duration curve for the single Equivalent station
  - D: Detailed model of the hydropower system
  - Eq(a): Baseline aggregation
  - Eq(b-d): Computed Equivalent based on bilevel problem formulation